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Original Article

Scale model of a new midwater trawl system for sampling pelagic larval and juvenile fish

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SUMMARY: A new midwater sampling trawl was designed to collect pelagic larval and juvenile fish. It has a rigid square frame of 2.25 m^2, with a 12.5 m high strength polyethylene net. The cambered V-type depressor with a camber ratio of 15%, aspect ratio of 6.0, and dihedral angle of 20° was hung to the bottom of the frame with four slings based on the principle of the parallelogram. A 1/5 scale model net of the prototype was made to examine the towing performances in a circulating water tank. The depth of the net and the attack angle of the depressor were measured at various flow velocities ranging from 30 to 100 cm/s with warp lengths of 260, 310, 360, 410 cm. The depressor held the setting angle closely, and the fluctuating range of the net depth was only 2% for the longest warp length over a wide range of flow velocities. This sampling trawl could maintain near constant depth under various flow velocities by the results of model experiment.

KEY WORDS: **attack angle, juvenile fish, larval fish, midwater trawl, model experiment, quantitative sampling, towing depth.**

INTRODUCTION

The quantitative and accurate sampling of larval and juvenile fish is necessary to clarify the mechanism and to estimate the abundance of recruitment. Hence, several kinds of midwater trawling gear have been developed to sample larval and juvenile fishes. The Issacs–Kidd midwater trawl (IKMT)[1] was designed to sample at fast speeds of 2–3 m/s. The 10 feet IKMT has a net-mouth area of about 7–8 m^2 with a V-shaped depressor of 3 m width. A disadvantage of the IKMT is the fluctuation of the towing depth depending on towing speed because the depressor is formed in the lower portion of the net-mouth. In the Tucker trawl[2] and the rectangular midwater trawl (RMT),[3] the bridle attaches only to the top of the net frame and they are usually equipped with an opening-closing mechanism for the net-mouth. A common design has a mouth area of 8 m^2 with a 291 kg weight in the lower bar. The drawback of this design is that the mouth angle to towing direction varies with the towing speed and consequently the mouth area changes. The towing speed is restricted to less than about 1.0 m/s accordingly. The frame trawl, a modified Issacs–Kidd trawl (MIKT)[4] was developed for sampling juvenile fish. The mouth of the net is surrounded with a rigid square frame and a flat V-shaped depressor is used. However, the attack angle of the depressor changes greatly with the towing speed because the depressor attaches to each of the midpoints of the opposite sides of the net frame by single slings. A fixed-frame trawl developed by Matuda *et al.*[5] for sampling Antarctic krill, can maintain constant sampling depth of the net at a wide range of towing speeds. However, the upper and lower kite built into the frame may disturb the flow of water near the net-mouth.

In order to overcome the disadvantages of these sampling trawls, we designed a new midwater trawl with a rigid square frame. This new midwater trawl equipped with a cambered V-type depressor and new attachment of the depressor to the net frame was adopted to retain the setting attack angle in any condition. A 1/5 scale model was used to examine the behavior of the cambered V-type

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depressor and the towing performance of a new sampling trawl with various towing speeds and warp lengths. Following this the performance and practicability of this new sampling trawl were compared to that of the MIKT.

MATERIALS AND METHODS

Theoretical consideration

We designed the cambered V-type depressor and confirmed the excellent performance with model testing.[6] However, in order to maintain a constant towing depth, the depressor hung from the net frame must always keep the setting attack angle irrespective of the towing speed to obtain sufficient sinking force. Thus, the cambered V-type depressor was hung beneath the net frame with four mutually parallel slings based on the principle of the parallelogram (Fig. 1).

To describe the dynamic balance of this sampling trawl, we assumed that the resistance and underwater weight of the net act on O-point (Fig. 2). Then, the equilibrium equation of the forces in O-point can be written as follows when the sampling trawl is towed at steady state:

$$T\cos\theta = \frac{1}{2}(R_n + D), \tag{1}$$

$$T\sin\theta = \frac{1}{2}(L + W_n + W_p), \tag{2}$$

$$M_0 = F_1 \cdot \sin(\alpha + \phi) \cdot r - F_2 \cdot \sin(\alpha + \theta) \cdot p, \tag{3}$$

where R_n is drag and W_n is the underwater weight of the net; M_0 is the moment which rotates around the O-point; F_1 and F_2 are tension of the slings; L is sinking force, D is the drag, and Wp is the underwater weight of the depressor. Moreover, the sum of r and p is equal to c: the cord length of the depressor. From Eqns 1–3:

$$T = \frac{1}{2}\sqrt{(R_n + D)^2 + (L + W_n + W_p)^2}, \tag{4}$$

$$\theta = \tan^{-1}\frac{L + W_n + W_p}{R_n + D}. \tag{5}$$

When the warp angle θ to the towing direction is kept constant and if the effect of the resistance and weight in water of the warp can be disregarded, the sampling trawl can be towed at a constant depth stratum over a wide range of towing speeds. In this case, when adjusting for weight in water of the net which contains the depressor to become zero, from Eqn 5, the following equation can be written as:

$$\theta = \tan^{-1}\frac{C_L}{C_N \cdot \dfrac{A}{S} + C_D}, \tag{6}$$

where C_L and C_D are the sinking force coefficient and the drag coefficient of the depressor, respectively. C_N is the drag coefficient of the net; A is the mouth area of the net; and S the wing area of the depressor. C_L, C_D and C_N are given by following equations:

$$C_L = \frac{2L}{\rho S V^2}, \tag{7}$$

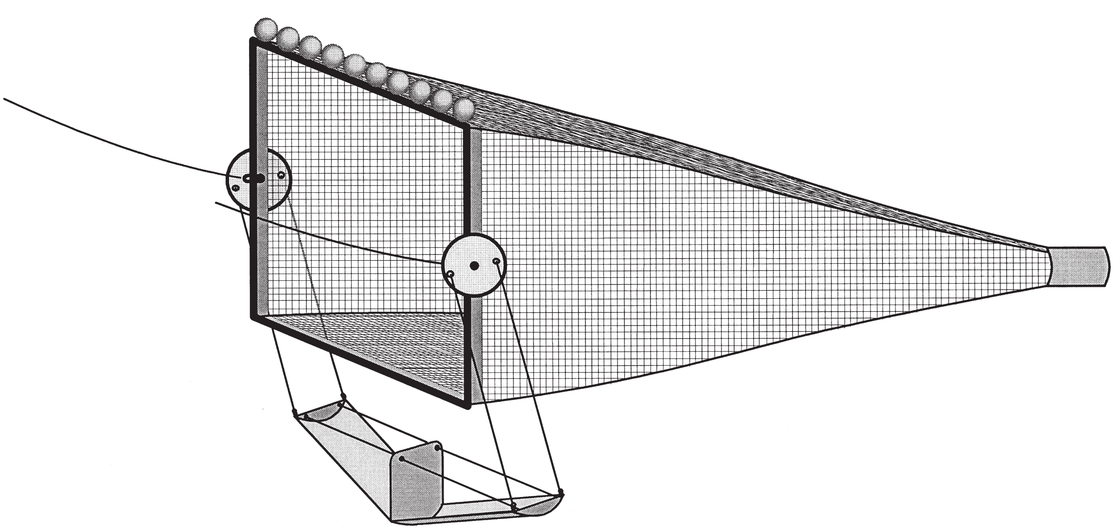

Fig. 1 Profile of the midwater sampling trawl developed by this research.

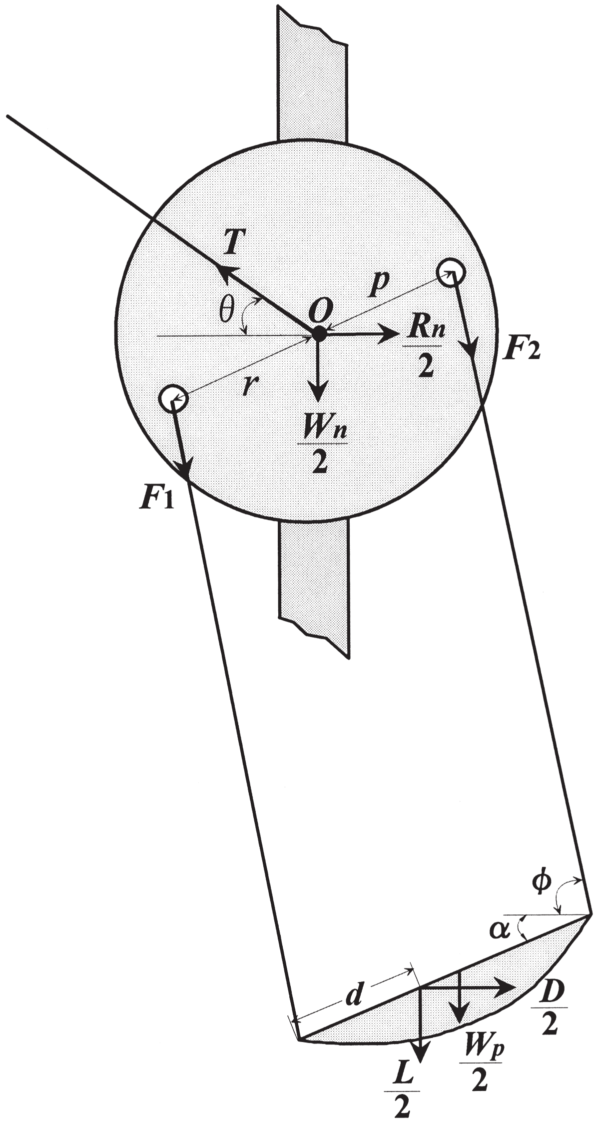

Fig. 2 The balance of forces which act on the midwater sampling trawl. R_n, drag of the net; W_n, weight of the net in water; W_p, weight of depressor in water; L, sinking force of depressor; D, drag of depressor; T, warp tension; θ, warp angle to towing direction; α, attack angle of depressor; ϕ, sling angle to towing direction.

$$C_D = \frac{2D}{\rho S V^2}, \tag{8}$$

$$C_N = \frac{2R_n}{\rho A V^2}, \tag{9}$$

where V is the towing speed, and ρ is the density of fluid. If the resistance of the net, the sinking force and the drag of the depressor are proportional to the square of the towing speed, and the attack angle of the depressor is also always kept at a constant value, then the warp angle becomes constant. Consequently, the sampling trawl can be towed at a constant depth stratum regardless of towing speed.

To prevent the tilt of the net frame due to the moment of the underwater weight and hydrodynamic force of the depressor, it is necessary to satisfy the condition shown as:

$$F_1 \sin(\alpha+\phi)\cdot r = F_2 \sin(\alpha+\phi)\cdot p \tag{10}$$

From Eqn 10, the following equation can be written as:

$$\frac{r}{p} = \frac{\frac{d}{c}\cdot N + \frac{1}{2}W_p\cdot\cos\alpha}{\left(1-\frac{d}{c}\right)\cdot N + \frac{1}{2}W_p\cdot\cos\alpha}, \tag{11}$$

where d is the distance from the former edge to the pressure center of the depressor and N (=$L\cdot\cos\alpha + D\cdot\sin\alpha$) the fluid resultant force of the depressor. In addition, if underwater weight of the depressor can be disregarded compared with the fluid resultant force of the depressor, the next equation is obtained.

$$\frac{r}{p} = \frac{d}{c-d}. \tag{12}$$

If the ratio of r to p for attaching the depressor to the net frame with two slings in each side shown in Fig. 2 is adopted according to Eqn 11 or 12, then the tilt of the net frame due to the depressor will be avoided.

Construction of the new trawl

The prototype midwater sampler we developed has a rigid mouth frame made of stainless steel with dimensions of 2.25 m × 2.25 m in the inside width. The high-strength polyethylene net of 12.5 m long is made with knotless square mesh of 1.95 mm bar length and 0.36 mm twine diameter.

The cambered V-type depressor with an aspect ratio 6.0, a camber ratio 15%, and a dihedral angle 20° is used. The wingspread of the depressor is 2.44 m, the same as the outside width of the net frame, and its wing area is 0.99 m^2. The depressor was attached to the midpoints of two opposite sides of the net frame using two mutually parallel slings at each end based on the principle of the parallelogram (Fig. 2). The setting attack angle of the depressor was 25°. The underwater weight of the net with the depressor was adjusted to zero with the float attached to the upper side of the frame according to the mentioned theory (Fig. 1). This midwater sampling trawl is called MOHT (Matuda, Oozeki & Hu Midwater Trawl).

Model experiment

To examine the performances of the MOHT, the 1/5 scale model of the prototype was made according to Tauti's model law.[7] The depth of the net and the attack angle of the depressor were measured by changing the flow velocity and the warp length in a circulating water tank at the Tokyo University of Fisheries. The same netting was used in both the prototype and the scale model net.

In the model experiment, the warp lengths used were 260, 310, 360, and 410 cm, and the flow velocity was set between 30 cm/s and 100 cm/s at 5 cm/s intervals at each warp length. The warp was a stainless wire of 2.0 mm in diameter. The depth of the net was measured with two micro pressure sensors installed at the midpoints of two sides of the mouth frame. In order to examine the change in the drag coefficient of the net in relation to flow velocity, the drag of the net without the depressor was measured with the flow velocities ranging from 20 cm/s to 90 cm/s at 5 cm/s intervals. In addition, a 1/5 model net was made of the modified Issacs–Kidd midwater trawl (MIKT) which attached the flat V-shaped depressor with the same dihedral angle as the cambered V-type depressor, and the experiment was carried out in the same manner as with MOHT.

RESULTS AND DISCUSSION

Change in drag coefficient of net in relation to the Reynolds number

The drag coefficient of the net should become constant in relation to Reynolds number, so that the sampling trawl may tow at a constant depth as shown in Eqn 4 regardless of the change in towing speed. The relation of the drag coefficient of the net C_N to the Reynolds number R_e ($= V{\cdot}b/\nu$) based on the width (b) of the net-mouth is presented in Fig. 3. From this figure, C_N tended to increase a little when Reynolds number was smaller than 1.5×10^5. But, if the Reynolds number was larger than 1.5×10^5, C_N hardly changed. The average of C_N was 1.16, with a fluctuating range of ±5% over the various flow velocities (20–90 cm/s). In a usual trawl net, the drag of the net is not proportional to the square of the towing speed because the net-mouth is easy to change by the towing speed. Consequently, the drag coefficient of the net becomes smaller with an increase in the Reynolds number.[8] As shown in Fig. 3, it is guessed that the drag coefficient of the net was almost constant regardless of the Reynolds number because a rigid mouth frame was used for this sampling net.

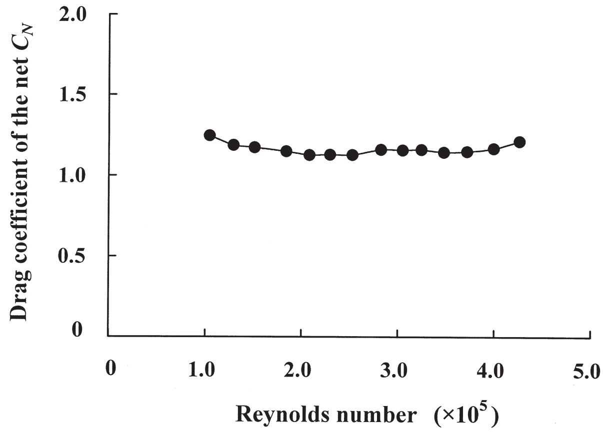

Fig. 3 Relationship of drag coefficient to Reynolds number on the model net.

On the other hand, high-strength polyethylene was used in the netting material of this MOHT, and accordingly, the thin twine became usable to increasing the filtration efficiency. The estimated drag of the full scale net from the model experimental results was 750 kg at a towing speed of 1.5 m/s and increased to 1330 kg at 2.0 m/s. If the nylon netting is used with the same bar length as this design, thick twine must be used to maintain the strength of the netting, and the drag of the net also increases. Therefore, we believe that the drag of the high-strength polyethylene net design was considerably reduced compared with the net made from the nylon material.

Attack angle of cambered depressor

The photographs at the 260 cm warp length in each flow velocity of 40, 60, 80, 100 cm/s are shown in Fig. 4. We observed that the cambered V-type depressor hung with four slings from the net frame maintained almost the same setting attack angle under flow velocities ranging from 40 to 100 cm/s. Also, tilting of the net frame either forward or back was not observed. The attack angles of both the MOHT and the MIKT measured at each flow velocity by the model experiment are shown in Table 1. The setting warp length of both types is also 260 cm. The attack angle of the depressor on the MIKT sampling trawl was 52.0° in 45.1 cm/s flow velocity and changed to 83.5° when the flow velocity increased to 60.1 cm/s. Thus, the attack angle of the depressor varied 31.5° with a slight flow velocity increase of 15 cm/s. At the 60.1 cm/s flow velocity, the depressor swung in farther back and its angle became almost vertical to the flow,

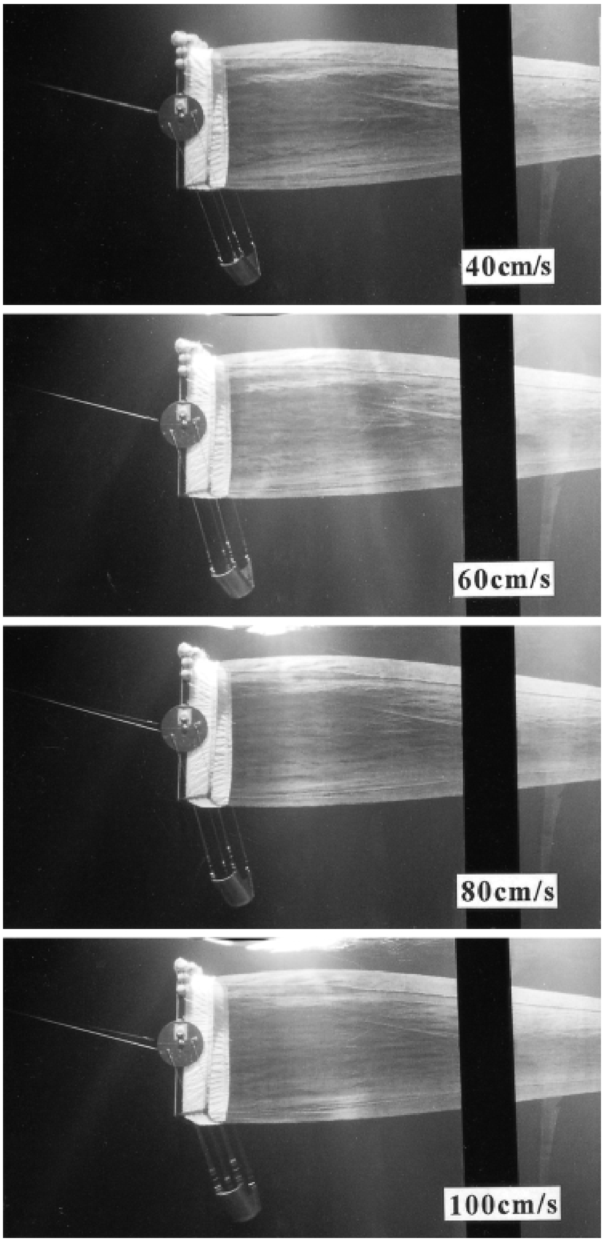

Fig. 4 Changes in attack angle of the cambered V-type depressor for the Matuda, Oozeki & Hu Midwater Trawl (MOHT).

Table 1 Variations of the attack angle of depressor for MOHT type and MIKT type sampling trawl in relation to flow velocity

MOHT type		MIKT type	
Flow velocity (cm/s)	Attack angle (°)	Flow velocity (cm/s)	Attack angle (°)
40.9	24.5	45.1	52.0
59.7	25.0	50.5	59.0
80.9	25.5	55.7	73.5
99.1	25.5	60.1	83.5

MOHT, Matuda, Oozeki & Hu midwater Trawl; MIKT, modified Issacs–Kidd trawl.

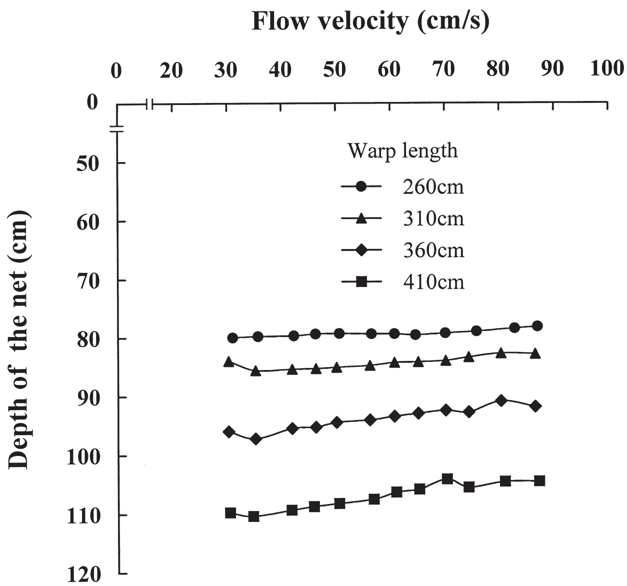

Fig. 5 Variations of depth of the Matuda, Oozeki & Hu Midwater Trawl (MOHT) in relation to the flow velocity at different warp length.

and the sinking force was not obtained. Consequently, the net geometry was also affected by blowing the depressor to the back of the net-mouth. On the other hand, the variations of the attack angle for the MOHT were within ±5° over a wide range of the flow velocities (Table 1). It is very important for the depressor to maintain a setting attack angle for the sampling trawl to tow at a constant depth regardless of the towing speed.

Change in depth of net in relation to flow velocity at different warp lengths

From the results of the model experiment, the drag coefficient of the net was almost constant, and the depressor hung from the frame was able to keep the setting attack angle over a wide range of flow velocities. Disregarding the effect of the warp, a new sampling trawl (MOHT) will be able to tow at a constant depth. We examined the change of the net depth in relation to the flow velocity and warp length (Fig. 5). Warp lengths were 260, 310, 360, 410 cm and flow velocities ranged from 30 to 85 cm/s at each warp length. At warp lengths of 260 cm or 310 cm, it is clear that the net maintained almost constant depth in the range of flow velocities. However, when the warp length increased to

360 cm or 410 cm, the depth of the net slightly decreased as flow velocity increased. Overall, the average depth of the net at warp lengths of 260, 310, 360, 410 cm were, respectively, 79.3, 84.3, 93.7 and 107.1 cm. The fluctuating ranges for mean depth of the net were 0.7, 1.1, 2.0, and 2.0%, respectively. Even at the longest warp length of 410 cm, the fluctuating range was only 2.0%.

Through experimentation in a circulating water tank, the depressor on the scale model always maintained the setting attack angle and this stability of the angle allowed the net to be towed at a constant water depth over a wide range of flow velocities. The new method with a hanging depressor can keep a setting attack angle under any conditions, and consequently the depth of the net will certainly be able to be controlled by the warp length.

The MOHT designed in the present study did not consider the effect of the hydrodynamic force and underwater weight of the warp on the towing depth of the net. Sea trials using the prototype should be carried out to address this problem.

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